Reviewer 2:

We are very grateful for your thoughtful feedback. In responding to each point, your comment helped make meaningful improvements to the manuscript's clarity and readability.

Question 1:

It seems that the patterns that emerge in MJJ 2023 mirror known biases in precipitation from models and reanalysis. Is there anything to be learned from this similarity?

Response:

Thank you for this keen observation. We agree that this is a valuable point to consider, and a useful reminder that moisture source regions identified by WAM2layers are inherently shaped by the biases present in the original input meteorological data. In our case, this is ERA5. The answer to your question would also be a great addition to our future work section, so we have added this new paragraph below to line 563 in the original text.

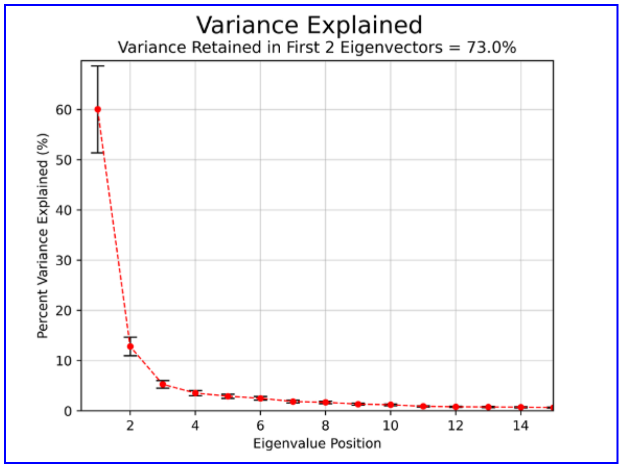
> "Another promising direction for future work would be to systematically perturb the initial meteorological conditions in the input dataset and rerunning the WAM2layers with each perturbed dataset. For instance, if future studies were to perturb ERA5 data within its range of uncertainty or error, it could create an ensemble of WAM2layers output to assess how sensitive the moisture source patterns are to the original input data. Comparing results using ERA5 against an alternative input dataset, such as PRISM, could further help evaluate the robustness of moisture source identification across different meteorological products. While this is outside the scope of the current study, we view it as a valuable direction for future research."

Question 2:

Are you able to say how much the EOF1 pattern explains the anomalous precipitation observed during 2023? Even though 2023 received most of its moisture from its typical sources, there were a few minor source regions whose percent contributions nevertheless changed considerably (Fig. 5). It makes me wonder whether a few minor PC modes actually contributed quite significantly to the 2023 precipitation patterns.

Response:

Thank you for this intriguing question, we have enjoyed exploring how to answer it. Unfortunately, we are unable to speculate on the importance of minor EOF modes. As shown in Figure 8 (attached below for convenience), the error bars for eigenvalues 1 and 2 are well separated from each other and from the remaining modes, indicating these two modes are statistically distinct. Beginning at eigenvalue 3, however, the error bars overlap substantially and become indistinguishable from one another, so we cannot claim individual physical significance for EOF3 and beyond. Future work incorporating additional May-July seasons could potentially render eigenvalues beyond EOF2 distinguishable. This is an interesting question, but one we are unable to explore further here.



One thing to point out is that Figure 5 describes each region's evaporative contributions relative to their average contributions. Minor source regions, like the Southern US and Gulf of Mexico, showed considerably large increases in moisture contribution to the Front Range in May-July of 2023. However, we note that as shown in the table below, the overall importance of these minor source regions can seem deceptively large when considering their actual contribution.

	Percent of Average Contribution Figure 5	Average Contribution (millions of m^3) Data not shown directly in paper	May-July Contribution (millions of m^3) Table 1
Southern US	401%	88	354
Gulf of Mexico	276%	100	275
Western US	180%	757	1,354
Pacific Ocean	153%	341	2,367

After answering your question we have also decided that this information is relevant to other potential readers of this paper and explains further the limitations of our analyses. Below is the newly added text inserted on line 401 in the original text.

> "Error bars for eigenvalues one and two are well separated from each other and from the remaining modes, indicating these two modes are statistically distinct. Beginning at eigenvalue three, however, the error bars overlap substantially and become indistinguishable from one another, so we cannot claim individual physical significance for EOF3 and beyond."

Comment 3:

In Line 89, Appendix B is mentioned before A, which feels odd. Moreover, B contains no text contextualization and feels more supplementary to the article (rather than essential for interpreting the results). Would it be worth considering moving B material to SI instead?

Response:

We agree with the reviewer's suggestion. Since the additional sink region analyses are not essential to the study's main conclusions, Appendix B is better suited to the Supplementary Information files. Similarly, we've moved Figure A4 (the map of Colorado's alternate climate divisions) to the SI, since Figure 2 already shows the Front Range region's location. As there's no accompanying text for the other Alternate Climate Divisions, keeping Figure A4 in the Appendix would be redundant, and it fits more naturally in the SI.

Comment 4:

Figure 3 - please describe the pink outline in the caption.

Response:

Thank you for this comment; we have added this text to the end of Figure 3 and Figure 5's caption:

> "The Front Range region is outlined in red on the map."

Comment 5:

I recognize that the source region map (Fig A5) is provided in the appendix, but I actually think the map is critical for communicating the paper's main results. At the least, please refer readers to the map from the main text, not just from the figure captions.

Response:

Thank you for this comment. We decided to move Figure A5 into the main text. Moisture contributions from specific defined regions are central to the conclusions of this paper, and the definition of these regions should therefore be included in the Methods. We have moved Figure A5 to Section 2.2, thus, renaming Figure A5 to Figure 2. To ensure proper introduction to this figure we also edited wording of what was line 160 in the original text as follows:

> "For reference, the geographic definition for each source region is provided below in Figure 2."

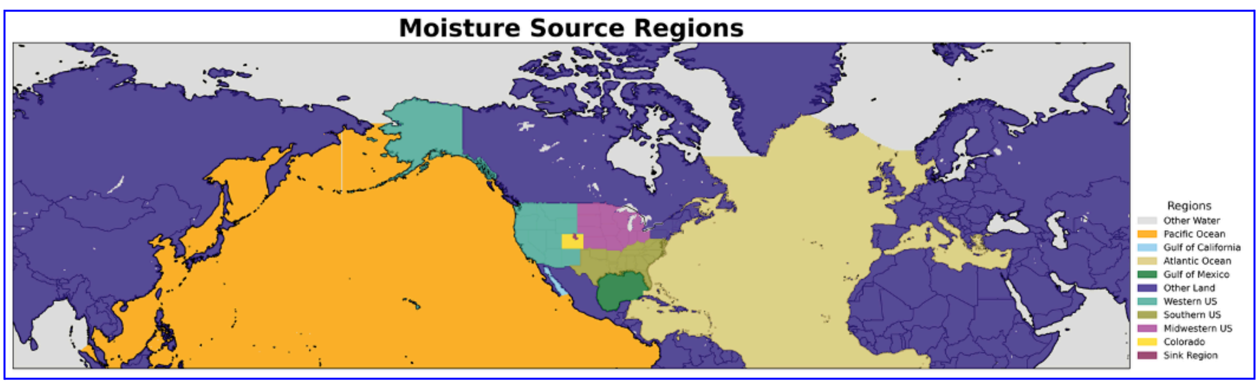


Figure 2: Classification of moisture source regions. Broad ocean regions follow the Global Oceans and Seas dataset (Flanders Marine Institute, 2021), and suboceanic regions, including the Gulf of

Mexico and Gulf of California, are defined using International Hydrographic Organization boundaries (Flanders Marine Institute, 2018). Land-based regions are based on the U.S. Census Bureau regional divisions. The sink region shown here is the Front Range, but changes depending on the sink region.

Comment 6:

Line 289 states that Jun '23 received the most anomalous precipitation. I could not find this shown anywhere in the figures or tables, and I also wondered if this wouldn't fit better in Section 3.2, which discusses how anomalous 2023 was compared to other years.

Response:

Thank you for pointing this out, we agree that this information is not presented in Table 1 as mentioned in the text; we have corrected the error. The following paragraph now reads as:

> 'In June, terrestrial sources were responsible for over half of Front Range precipitation, with aquatic sources contributing slightly less than half (Table 2 and Figure 3.d). The Pacific Ocean and Western US remained the most contributing regions….'

June 2023 did receive the most anomalous precipitation as shown in Table 3 in the final row. In agreement with your suggestion, we have moved this line to Section 3.2 and rewrote it to avoid future confusion. You can now find it inserted after line 348 in the original text as:

> '....Among all months in 2023, June was the most anomalous relative to their historical average, receiving more than double its typical rainfall (Table 3).'

Comment 7:

Line 353 indicates that there are three regions responsible for most of the anomalous precipitation. I understand that these regions provided the most precipitation; however, according to Fig 5, they showed some of the least anomalous percent changes. A little care with wording here would be beneficial for your readers.

Response:

We thank the reviewer for pointing this out and agree that the wording here should be more careful.Thus, we have deleted the word 'anomalous' from the sentence so line 353 (from the original text) now reads as:

> "The Front Range received more total moisture from all source regions, with the Pacific Ocean, Western US, and Colorado responsible for most of the ~~anomalous~~ precipitation during this extremely wet season. Contributions from eastern regions such as the Southern US, Midwestern US, and Gulf of Mexico delivered up to four times the amount of water they usually do but were not responsible for most of the ~~anomalous~~ precipitation during this time period."

However, I would like to point out that the original statement is true. Although the Southern US, Gulf of Mexico, and Western US show relatively small percent changes in Figure 5, their average moisture contributions are large in absolute terms, meaning their anomalous contributions of water vapor may be larger than their percentage of average alone suggest. The table below illustrates this point.

	Percent of Average Contribution Figure 5	Average Contribution (millions of m^3) Data not shown directly in paper	Anomalous Contribution (millions of m^3) Table 1 minus average contribution
Southern US	401%	88.2	265.4
Gulf of Mexico	276%	99.5	175.2
Western US	180%	756.9	597.6
Pacific Ocean	153%	340.9	820.6

Comment 8:

Section 3.3 talks about clustering "tracked evaporation anomalies." It took me a while to understand exactly what this meant. Consider unpacking this phrase for your reader. It is relevant for readers to understand how the anomalies are calculated.

Response:

Thank you, we fully agree with your comment. To ensure clear communication, we added additional text in our K-means Clustering methods (section 2.5) and revised the text on line in Section 3.3 to direct the reader there.

Newly added text beginning on line 200 in Section 2.5:

> "To identify how moisture sources in May-July of 2023 compared to previous, individual seasons, we applied a k-means clustering analysis to tracked-evaporation anomalies from 2000 to 2023. Specifically, anomalies were calculated by first summing tracked evaporation across May, June, and July for each respective year, then subtracting the 2000 to 2023 climatological mean tracked evaporation at each gridcell gridcell."

Rewritten text beginning on line 358 in Section 3.3:

> "To further contextualize the MJJ moisture sources in 2023 against other individual MJJ seasons, rather than a multi-year average, we applied a k-means clustering analysis on anomalous seasonal tracked evaporation from every MJJ season in 2000 to 2023. A detailed description on how these anomalies were calculated can be found in Section 2.5."

Comment 9:

There are a few other places where the text is difficult to follow. They are: Lines 142-144, and Lines 249-250

Response:

We appreciate your comments and have rewritten lines 142-144 from, "We backtracked Front Range precipitation from 19 December 2023 to 1 January 2000. However, in our analysis, we do not include data from December, November, October, nor September of 2023 to allow more than three months of spin-up time for the model."

To this revised version,

"In our analysis, we use backtracked precipitation from August 31st to January 1st 2000."
It is typical to remove the first few weeks of model output to ensure moisture source data is not an artifact of initial start up conditions. Since the WAM2layers tracks precipitation backwards in time to their estimated evaporated origin, in this model's case, output is produced from most recent data to later in time. Thus, spin up time is from output in late 2023."

We agree and have also better clarified the content in lines 249-250. We have revised the explanation and relocated it to the Methods section (Section 2.2), since it clarifies terminology and describes our analytical approach rather than presenting a result. It now appears after line 154. In its original location (Lines 249–250), we have deleted this text.

Original text in lines 249-250:

"Moving forward, total annual or total monthly tracked evaporation may also be referred to as annual or monthly total precipitation, subject to the limitations outlined above."

Newly created text in section 2.2, beginning on line 154:

"To clarify terminology, globally-summed or total tracked evaporation and total precipitation are used interchangeably. This equivalence holds due to the conservation of atmospheric moisture inherent in the WAM2layers model (van der Ent and Tuinenburg, 2017; Gimeno et al., 2021). This conservation means that no moisture is created or lost in the tracking process. The total tracked evaporation across all grid cells in our domain must balance the total precipitation received in the Front Range over the same period. We therefore sum the 2D monthly tracked evaporation variable across all grid cells as an approximation of total monthly precipitation throughout the manuscript."

Comment 10:

Line 389: the same…sources, add "as other years."

Response:

We agree and have updated the text. Lines 388-90 will now read, "Although 2023 shared the same dominant moisture sources **as other years** (e.g. Colorado and the Pacific Ocean), the magnitude of contributions from those regions was dramatically higher than in any previous year (figure 7.d)."

Comment 11:

Like other sections, the discussion is well written and quite thorough. However, near Line 480, I noticed a strong emphasis on possible Southwest moisture source variability and little discussion of "western" sources, which seem to be quite important for 2023.

Response:

Thank you for bringing this point up. We agree the original text was unclear about how the Skinner et al. (2023) comparison relates to our results, and we will revise this discussion near Line 480.

To clarify, ‘Southwest’ in line 476 refers to the sink region defined in Skinner et al. (2023), which covers a much larger area spanning Colorado, Utah, Arizona, and New Mexico. Unfortunately, very few existing studies use sink regions that overlap with our Front Range domain or quantify moisture contributions from the Western U.S. We therefore use Skinner et al. (2023) as one of the closest available points of comparison, despite this difference in sink region definitions. Since moisture sources and recycling ratios are strongly dependent on the size and location of the study region, we can only draw broad comparisons between our findings and their results for the much larger Southwestern domain. Hence why we were unable to directly situate our Western U.S. findings within this existing literature.

We have revised the original paragraph beginning on line 474 to clarify this distinction. Below, newly added text is bolded and deleted text is striked through.

The revised paragraph is as follows:

> “Our conclusions were somewhat difficult to corroborate since the 2023 extremes were so recent that no peer-reviewed studies had been published at the time of this writing. There is, however, literature examining moisture sources during historically wet seasons for **a much larger, overlapping region,** the ~~entire~~ Southwestern United States. Based on this, we can ~~qualitatively review how 2023 moisture sources broadly compare to sources during other wet years~~ **compare moisture recycling in the Front Range during May-July of 2023 to recycling patterns reported for other wet seasons in the broader Southwest as shown in Skinner et al. (2023).** ~~Skinner et al. (2023)~~ **That study** found that during the wettest summers (June, July, August) in the Southwestern United States, the percent change in moisture ~~from areas inside the region~~ **contribution from the sink region itself** ~~compared to normal~~ increased by 42% and from areas outside of the Southwest, increased by 48% (Skinner et al., 2023). This could suggest that during wet years in the Southwest, there is a widespread increase in moisture content from nearly all source regions, rather than a singular anomalous import from a specific source region. Our findings indicate a similar pattern. We found that Colorado's Front Range received anomalously high precipitation contributions from all dominant moisture source regions. To truly understand the potential mechanism of enhanced wet season precipitation, additional modelling and analysis beyond the scope of this work would be required.”

Reference:

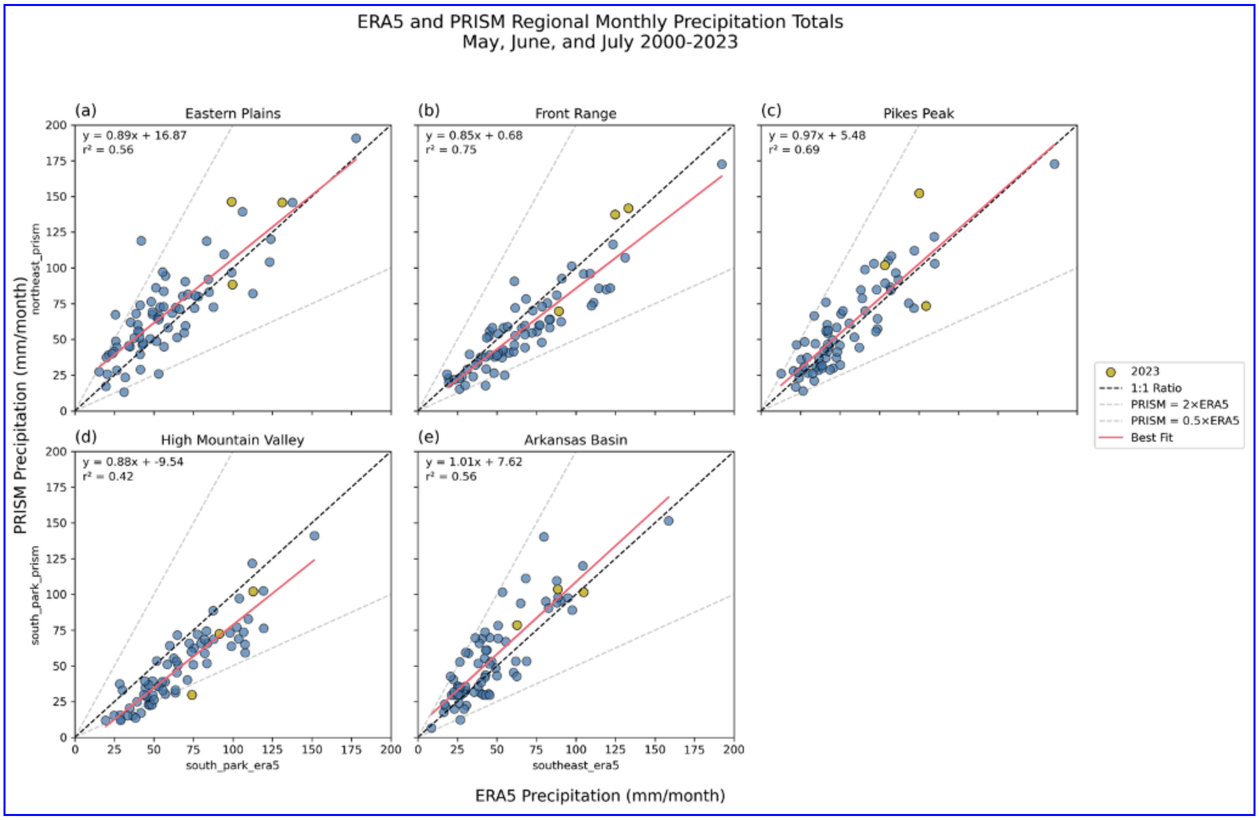
Skinner, C. B., Harrington, T. S., Barlow, M., and Agel, L.: The contribution of precipitation recycling to North American wet and dry precipitation extremes, Environ. Res.: Climate, 2, 045010, https://doi.org/10.1088/2752-5295/acffea, 2023.

Comment 12:

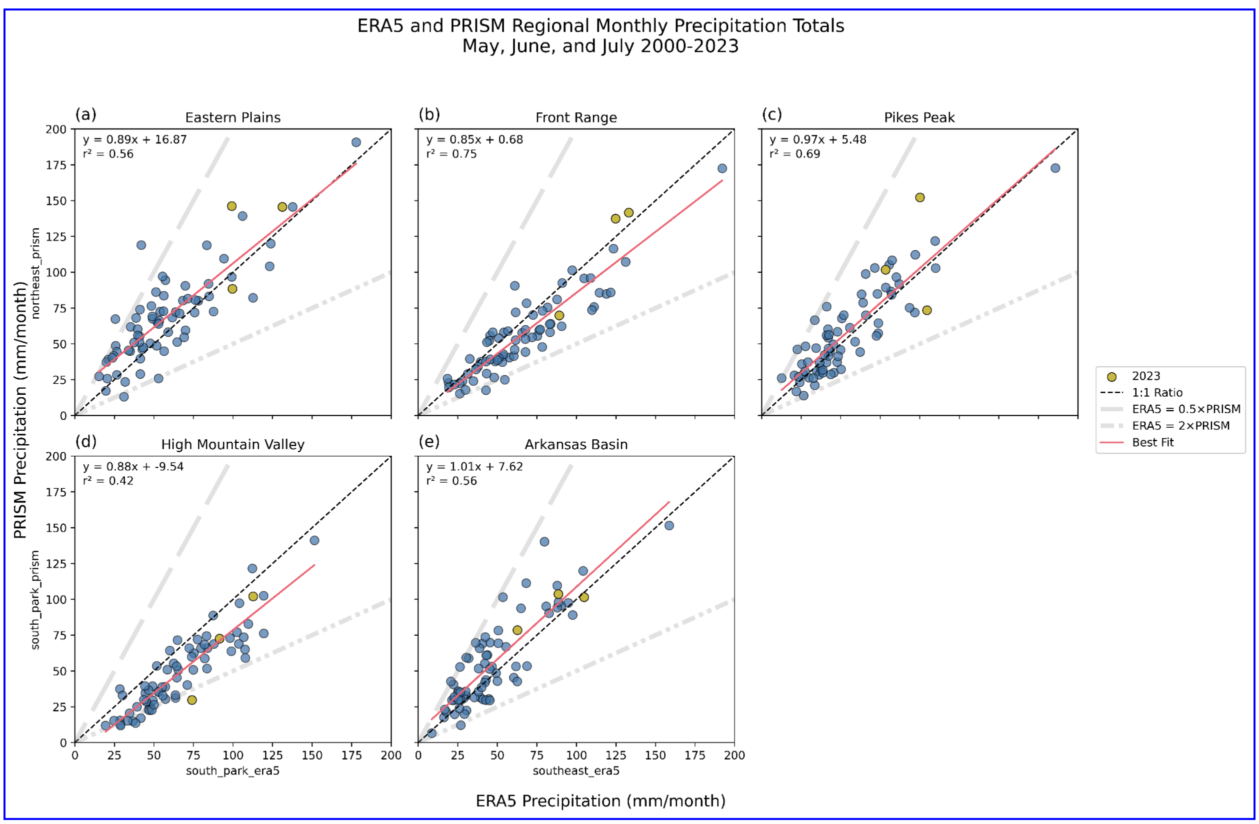
Figure A1: it is difficult to make out the 2x and 0.5x lines. Also, the caption says “source regions” but the main text calls them “sink regions.” Is this a typo?

Response:

We agree that it is difficult to discern these lines, so we have increased the line width of the 2x and 0.5 lines, differentiated the line style such that each grey line is not identical to one another. We have also updated the caption to correct the typo. Below is a side by side comparison of the original Figure A1:



And the updated Figure A1 with caption changes are bolded:



"A1: Comparison of ERA5 and PRISM monthly precipitation totals summed across **sink** regions (ex. **Front Range**). Only plotting precipitation totals in the months of May, June, or July. May-July of 2023 is plotted as yellow markers. Best fit line plotted in red**,** and slope, y-intercept, and r^2 value annotated in the top left corner. **The black dashed line marks 1:1 agreement between ERA5 and PRISM. The grey dashed and dash-dot lines mark where ERA5 is half and twice the PRISM-estimated precipitation, respectively."**

COMMENT 13:

Figure A6 "percent error overtime" should be "over time"?

Response:

Indeed it should, however, we have removed the over time altogether, so the graph now says "Percent Error".

Below is the updated Figure A6: